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Sharing a Mental Number Line Across Individuals?

The Role of Body Position and Empathy in Joint Numerical Cognition

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Abstract

A growing body of research shows that the human brain acts differently when performing a task together with another person than when performing the same task alone. In this study we investigated the influence of a co-actor on numerical cognition using a joint random number generation task (RNG). We found that participants generated relatively smaller numbers when they were located to the left (vs. right) of a co-actor (Experiment 1), as if the two individuals shared a mental number line and predominantly selected numbers corresponding to their relative body position. Moreover, the mere presence of another person on the left or right side, or the processing of numbers from loudspeaker on the left or right side had no influence on the magnitude of generated numbers (Experiment 2), suggesting that a bias in RNG only emerged during interpersonal interactions. Interestingly, the effect of relative body position on RNG was driven by participants with high trait empathic concern toward others, pointing towards a mediating role of feelings of sympathy for joint compatibility effects. Finally, the spatial bias emerged only after the co-actors swapped their spatial position, suggesting that joint spatial representations are constructed only after the spatial reference frame became salient. In contrast to previous studies, our findings cannot be explained by action co-representation because the consecutive production of numbers does not involve conflict at the motor response level. Our results therefore suggest that spatial reference coding, rather than motor mirroring, can determine joint compatibility effects. Our results demonstrate how physical properties of interpersonal situations, such as the relative body position, shape seemingly abstract cognition.

Keywords: mental number line, random number generation, joint action, joint Simon effect, empathy, Interpersonal Reactivity Index (IRI)

Introduction

Humans are a social species, and coordinated actions with other persons, such as carrying heavy objects or dancing, are an integral part of everyday life. Neuroscientists have started to realize that studying the human mind isolated from social contexts may be insufficient for a comprehensive understanding of cognitive processes. Several cognitive functions are shaped, or only exist, to allow inter-personal actions (van der Wel, Sebanz, & Knoblich, 2016). In the last decade, the research field of “joint action” has rapidly emerged and has started to unveil the neurocognitive principles of coordinated social actions (e.g., Novembre, Sammler, & Keller, 2016; Sebanz et al., 2006; Wriessnegger, Steyrl, Koschutnig, & Müller-Putz, 2016).

A seminal example of how brains work differently in joint (vs. single) tasks was provided by Sebanz, Knoblich, and Prinz (2003). In their study, two participants performed a joint reaction time task. Each participant controlled one of two response keys (left or right) and responded to a non-spatial stimulus dimension (red vs. green) of leftward or rightward pointing stimuli. Although the spatial information of the stimulus was task-irrelevant, there was a compatibility effect when the stimulus orientation corresponded to the side of response (i.e., a Simon effect; Simon, 1969). Crucially, such an effect was absent when each participant performed the identical single-key go-nogo task alone, showing that the spatial compatibility effect was the result of interacting with the co-actor. The authors concluded that a shared task representation and the integration of the co-actor’s action into one’s own action plan is crucial in joint action (Sebanz et al., 2003). The joint Simon effect has since been replicated and extended (Dolk et al., 2014).

The exact mechanism behind such joint compatibility effects is still under debate. On the one hand, it has been suggested that the cortical mirror neuron system plays a crucial role in this process by covertly simulating the co-actor’s action in the motor system (e.g., Gallese, Keysers, & Rizzolatti, 2004; Iacoboni et al., 2005). Accordingly, this motor simulation may

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drive the joint compatibility effect because it leads to a conflict for ‘go’ responses when the irrelevant spatial stimulus dimension primes the co-actor’s response (Atmaca, Sebanz, Prinz, & Knoblich, 2008; Sebanz et al., 2003). This suggestion is in line with *ideomotor theory*, claiming that anticipating another person’s motor response activates the same neuronal structures as when the responses were self-generated (Hommel, Musseler, Aschersleben, & Prinz, 2001). On the other hand, it has been suggested that the spatial reference frame resulting from the co-representation of others’ actions is the crucial aspect (Dolk et al., 2011; Guagnano, Rusconi, & Umiltà, 2010). Accordingly, the representation of the co-actor’s action provides a basis for coding one’s own actions relative to others. This account moves the focus away from the automatic co-representation of the co-actor’s stimulus-response rules to a more comprehensive view of referential event coding (Dolk et al., 2014), and implies that also one’s relative body position in space may play an important role for higher cognitive processes (cf. Mast, Preuss, Hartmann, & Grabherr, 2014).

The aim of this study was to further assess the mechanisms underlying joint compatibility effects and particularly the role of body position in joint cognition by means of a joint number task. Numbers are cognitively represented along a ‘mental number line’, with small numbers on the left and larger numbers on the right side of space (Fischer & Shaki, 2014). A frequently replicated observation is that left-sided responses are faster for small numbers and right-sided responses are faster for large numbers during number categorization tasks. This so-called SNARC (spatial-numerical association of response codes) effect (Dehaene, Bossini, & Giraux, 1993) also occurs when two persons share the task (Atmaca et al., 2008). In the present study we asked two persons to consecutively generate numbers as randomly as possible (RNG) while being located at a co-actor’s left or right side. Previous studies have established that the magnitudes of the ‘random’ numbers are sensitive to spatial manipulations. For example, participants generate smaller numbers during leftward than during rightward body motion (Hartmann, Grabherr, & Mast, 2012; Loetscher, Schwarz,

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Schubiger, & Brugger, 2008). In contrast to the joint SNARC task by Atmaca et al. (2008), the RNG task is lacking the conflict in the motor response because there is no cue that primes the co-actor's action alternative. Consequently, a numerical bias induced by the participants' relative positions in space cannot be explained by action co-representation (and mirror neuron system) accounts but rather by spatial referential coding. Regarding the specific effect of body position on RNG, two conflicting predictions can be made based on previous work. First, a recent study reported that the co-actor influences the randomness of one's own number sequence during joint RNG (Towse, Towse, Saito, Maehara, & Miyake, 2016), showing that the co-actors verbal output cannot be ignored. Processing the verbal information of another person to one's left or right is accompanied by shifts in spatial attention: It has been documented that perceiving a (task-irrelevant) sound shifts spatial attention automatically towards the side of the sound (Mazza, Turatto, Rossi, & Umilta, 2007; McDonald, Teder-Salejarvi, & Hillyard, 2000; Schmitt, Postma, & De Haan, 2000; Spence & Driver, 1997). Given the tight coupling between spatial attention in external space and representational number space (Fischer, Castel, Dodd, & Pratt, 2003; Longo & Lourenco, 2010; Zorzi, Priftis, & Umilta, 2002), attentional shifts toward the co-actor are therefore likely to influence RNG. A first hypothesis places the focus on the attention directed toward the co-actor and predicts that smaller numbers will be selected by participants located to the right of another person because their leftward attentional shifts toward their co-actor make smaller numbers cognitively more available (and vice versa for participants located to the left of another person). A second and competing hypothesis places the focus on the spatial reference frame induced by the dyad and predicts that the person on the right side of the dyad would generate larger numbers than when being on the left side because the joint SNARC effect suggests that processing larger numbers is facilitated when oneself is being located on the right side (Atmaca et al., 2008), or because of attentional withdrawal from the co-actor (Szpak et al., 2015; Szpak, Nicholls, Thomas, Laham, & Loetscher, 2016).

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Yet another open issue in the field of joint action is the extent to which joint compatibility effects are social in nature (Dolk et al., 2014). Since the accounts described so far are based on the (co)representation of others, one would expect that social aspects play a crucial role. In line with this view, several studies found that trait empathy of the actor moderates joint action effects (Ford & Aberdein, 2015; Novembre, Ticini, Schütz-Bosbach, & Keller, 2012), as does the quality of relationship between actors (Hommel, Colzato, & van den Wildenberg, 2009) and the perceived similarity between the actors (Iani, Anelli, Nicoletti, Arcuri, & Rubichi, 2011; Müller et al., 2011; Stenzel et al., 2012; Tsai, Kuo, Hung, & Tzeng, 2008). However, more recent studies ‘de-socialized’ joint compatibility effects by showing that also non-social events, such as a Japanese waving cat or a ticking metronome, are sufficient to influence individual task performance (Dolk et al., 2011; Dolk, Hommel, Prinz, & Liepelt, 2013). These authors concluded that joint spatial compatibility effects result from any salient event that serves as spatial reference for one’s own actions and are not necessarily social. Following this conclusion, the role of social aspects in our RNG task should be limited. In the present study, we measured participants’ trait empathy in order to further examine the ‘social nature’ of the joint compatibility effect. If the integration of another person into one’s own task representation is the crucial mechanism, then the spatial compatibility effect should be more pronounced for participants with high empathy (Ford & Aberdein, 2015; Novembre et al., 2012).

Finally, we assessed the role of the position change for the spatial compatibility effect. Participants changed their spatial positon with the co-actor halfway through the experiment, so that each participant generated numbers from the left and right side relative to their co-actor. Comparing the spatial compatibility effect before and after the position change will reveal whether the effect automatically occurs upon sharing a task, or conditionally only after the spatial frame of reference has been made salient by a spatial event (e.g., position change).

Experiment 1

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Method

Participants. Sixty-eight persons took part in Experiment 1 (48 female). The mean age was 25.4 years (*SD* = 11, 5). The sample consisted of undergraduate students (*n* = 60) and other persons from the private environment of the experimenter (*n* = 8). Participants gave written informed consent prior to the study. The study was approved by the local Ethics Committee.

Task and Procedure. In line with previous studies, participants were instructed to verbally state a sequence of numbers in the range of 1-30 as randomly as possible (Loetscher et al., 2008). Half of the participants (*n* = 34) performed the RNG task in a joint condition and the other 34 in a single condition. In a previous study, effects of empathy have only been found for actors that knew each other (Ford & Aberdein, 2015). We therefore decided to only investigate pairs of participants that were already acquainted. Participants who performed the RNG task in the joint condition were therefore recruited pairwise (they were acquainted by self report and considered themselves as colleagues or friends). In the joint condition, the two participants were seated next to each other in front of a table (see Figure 1). The starting positions (left, right) were randomly assigned to the participants within each pair prior to the experiment. Participants were instructed to alternatingly state random numbers at the pace of a metronome (0.66 Hz, presented by an ordinary laptop that was placed at the middle of the table). Participants were told to focus on the randomness of the own sequence and ignore the numbers of the co-actor. After each participant had stated 40 numbers, they switched their position and alternatingly stated another 40 numbers each. In the single condition, one participant stated 40 numbers sitting alone on one side of the table, followed by another sequence of 40 numbers sitting on the other side of the table (see Figure 1). Half of participants in the single condition started on the left, and the other half on the right side of the table. In order to mimic the characteristics of the joint condition, the laptop was placed next to the participant on top of a box on the empty chair, approximately at the position where

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the head of the co-actor would be. This was done in order to evaluate whether any spatial bias in the joint condition was induced by joining the task with the co-actor or rather by the non-social spatial frame of reference employed in this study (i.e., sitting on the left or right side of a table, hearing a sound from one's left or right side). Moreover, the pace of the metronome was set to 0.33 Hz, so that the frequency of generated numbers in the single condition was identical to the one of the individual sequence in the joint condition.

[Insert Figure 1 here]

During the experiment, the experimenter took place behind the participants (thus outside of their view), in a position centrally aligned to the table. In both conditions, participants were facing straight ahead and closed their eyes during RNG. Numbers were written down by the experimenter during the experiment, and they were also recorded by means of Audacity (run on the same laptop as the metronome sound). All numbers were checked offline by a person blind to the hypothesis.

After the random number generation task, participants filled out a personality questionnaire (see next section). At the end of the experiment, participants were asked to guess the aim of the experiment.

Assessment of Empathy. Trait empathy was measured using the Interpersonal Reactivity Index (IRI) (Davis, 1983). The IRI assumes that empathy consists of a set of four separate but related constructs: empathic concern, perspective taking, fantasy scale, and personal distress. *Empathic concern* captures one's tendency to experience feelings of sympathy and compassion for unfortunate others. Empathic concern does not simply reflect the sharing of emotional states with others but rather the internal state of emotion and motivation driven by the concern for another person's welfare (e.g., Bernhardt & Singer, 2012). *Perspective taking* captures one's tendency to adopt the point of view of others. Finally, *fantasy scale* focuses on one's tendency to imaginatively transpose the self into

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fictional situations, and *personal distress* on one's tendency to experience distress in emotional situations. We used the German version of the IRI (Paulus, 2009). The questionnaire consists of 16 questions (4 for each subscale), and responses were given on a 5-point Likert scale ranging from 1 = never to 5 = always. Participants used the online version of the questionnaire (http://bildungswissenschaften.uni-saarland.de/personal/paulus/empathy/SPF_SE.html) and the scores were automatically computed online and stored by the experimenter.

Results and Discussion

Data from one pair of participants in the joint condition and from two participants in the single condition was excluded from analysis because they did not follow task instruction (they generated obviously non-random sequences such as 2, 4, 6, 8 and so on). None of the participants guessed the hypothesis of this experiment.

The Role of Body Position. For each of the remaining 64 participants, the mean of generated numbers for each body position (left, right) was analyzed by a mixed-model analysis of variance (ANOVA) with the within-subject variable position (left, right) and the between-subject variable condition (joint, single). There was a significant main effect of position, $F(1, 62) = 6.17$, $p = .016$, $\eta^2_p = .09$. Overall, the mean of numbers generated on the left was lower than the mean of numbers generated on the right ($M_{left} = 14.5$, $SD = 1.5$; $M_{right} = 14.9$, $SD = 1.3$). There was no main effect of condition, $F(1, 62) = 0.71$, $p = .403$, $\eta^2_p = .01$ ($M_{joint} = 14.6$, $SD = 1.3$; $M_{single} = 14.9$, $SD = 1.3$). Most importantly, the two variables interacted, $F(1, 62) = 5.83$, $p = .019$, $\eta^2_p = .09$. Post hoc tests (paired *t*-tests) revealed a significantly lower mean of generated numbers when participants were sitting on the left than on the right side in the joint condition ($p = .002$; $M_{left} = 14.2$, $SD = 1.5$; $M_{right} = 14.9$, $SD = 1.3$), while there was no effect of body position in the single condition ($p = .959$, $M_{left} = 14.8$, $SD = 1.6$; $M_{right} = 14.8$, $SD = 1.3$; see Figure 2).

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[Insert Figure 2 here]

The Role of Empathy. The mean empathy scores for the four sub-scales was similar in both conditions (see Table 1). Independent *t*-tests confirm that there was no difference in the sub-scales between the two groups (all *p*s > .273). In order to assess a possible role of empathy for the influence of body position on RNG, empathy scores of participants in the joint condition were correlated with the individual difference between the averages of numbers generated on the right and left side ($RNG_{Diff} = M\ RNG_{right} – M\ RNG_{left}$). Positive RNG_{Diff} values indicate that higher average numbers were stated in the right (vs. left) position. There was a significant positive correlation for the subscale empathic concern (see Table 1). In order to further characterize the relationship between empathic concern and the spatial bias in RNG, participants were allocated to a low or high empathic concern group, based on the median split (median = 15). Four participants had a score of 15 (median) and were excluded from this analysis. The mean empathic concern score of the *high* group (*n* = 14) was 16.8, ranging from 16-20 (*SD* = 1.3), and the mean score of the low group (*n* = 14) was 12.4, ranging from 9-14 (SD = 1.7). Separate paired *t*-tests with the within-subject variable body position revealed a significant effect of body position only for the high empathic concern group, $t(13) = 4.26$, $p = .001$, $M\ RNG_{Diff} = 1.1$ ($SD = 1.0$), but not for the low empathic concern group, $t(13) = 0.24$, $p = .814$, $M\ RNG_{Diff} = 0.1$ ($SD = 1.2$).

[Insert Table 1 here]

The Role of Position Change. The analysis of body position revealed an effect of body position on the magnitude of generated numbers in the joint condition. We further analyzed this effect in order to explore whether the change in position was relevant for the emergence of the spatial bias. We conducted another ANOVA with the variables position (left, right) and position chance (before, after) for the joint condition. There was a main effect

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of position (as reported above) but no main effect of position change, $F(1, 60) = 0.11$, $p =$ 747, $\eta^2_p < .01$. Interestingly, these variables interacted, $F(1, 60) = 5.77$, $p = .019$, $\eta^2_p < .09$. Post-hoc tests (independent-samples *t*-tests) revealed that there was no difference between the left and right position *before* co-actors changed positions, $t(30) = -0.09$, $p = .927$ ($M_{\text{left}} = 14.5$, $SD = 0.3$; $M_{\text{right}} = 14.5$, $SD = 0.3$), but there was a significant difference *after* co-actors changed positions, $t(30) = -3.11$, $p = .004$ ($M_{\text{left}} = 13.9$, $SD = 0.3$; $M_{\text{right}} = 15.3$, $SD = 0.3$).

We also compared the mean magnitude of numbers between the left and right position after the the change in position for the single condition (by means of an independent sample *t*-test). There was no effect of position in the single condition after the change in position, $t(30) = 0.31$, $p = .760$ ($M_{\text{left}} = 14.9$, $SD = 1.4$; $M_{\text{right}} = 14.7$, $SD = 1.7$).

[Insert Figure 3 here]

The results so far point to a modulation of numerical cognition due to the construction of a spatial reference between the actor and the co-actor. Particularly, the actor seems to represent him-or herself as being located on the left or right side of the co-actor, and this biases the selection of numbers from the assumed mental number line (cf. Discussion). However, the nature of the effect found in Experiment 1 sill remains open because it is unclear whether the spatial bias was based on interpersonal interactions, or driven by the salient events provided by the co-actor (i.e., producing numbers on the actor's left and right sides). It has been argued that any salient event might lead to referential coding (Dolk et al., 2014) and therefore might potentially induce a bias in RNG.

These considerations raise two further questions. First, is the joint task performance with the other person mandatory for the bias in RNG, or does the *mere presence* of another person suffice to serve as spatial reference? And second, does the co-actor need to be a human being, or is the processing of numbers from one's left or right side (e.g. from a loudspeaker instead of a human co-actor) sufficient to induce a bias in RNG? To address these questions, a

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second experiment was performed in which the actor generated numbers alternating with a loudspeaker instead of a human co-actor. At the same time, another person was merely sitting at the same positon as the loudspeaker, serving as potential spatial reference point.

Experiment 2

Method

Participants. Twenty-four undergraduate students took part in Experiment 2 (17 female). The mean age was 22.6 years (*SD* = 1.7). Participants gave written informed consent prior to the study.

Task and Procedure. The procedure was identical to the joint condition from Experiment 1 with the following two exceptions: First, the experimenter (instead of another actor) took the place on the left or right side of participants. Second, participants did not generate numbers in turn with a human co-actor. Instead, pre-recorded random numbers (see below) were presented with a pace of 0.33 Hz through loudspeakers of a laptop that was positioned on participant's left or right side (the laptop was placed on the table in front of the experimenter). Thus, as in Experiment 1, participants stated numbers between 1-30 at an individual pace of 0.33 Hz (guided by a 0.66 Hz metronome tick) but this time in alternation with a "non-human co-actor". After participants had generated 40 numbers, they exchanged their position with the experimenter (and laptop) and generated another 40 numbers. Half of the participants started on the left, and the other half on the right side. In order to avoid any confound between the position and the magnitude of the numbers played through loudspeakers, two fixed pre-recorded number sequences (A and B) were used and counterbalanced at each position. The two sequences were created by generating two random sequences of 40 numbers from 1-30 ($M_{\text{Sequence A}}$ = 14.7, $M_{\text{Sequence B}}$ = 14.5) that were converted to soundfiles using a text-to-speech application (https://ttsreader.com; German voice, average duration of soundfiles = 633 ms). Half of the participants that started on the left side heard

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Sequence A, followed by Sequence B after the change of positon, and vice versa for the other half, and the same was true for participants that started on the right side.

Results

The mean magnitude of generated numbers was compared between the left and right position by means of a paired *t*-test. There was no effect of position, $t(23) = 0.15$, $p = .883$ ($M_{\text{left}} = 14.9$, $SD = 0.8$; $M_{\text{right}} = 14.9$, $SD = 0.9$). There was also no effect of position when only data after the change in position were considered, $t(22) = -0.27$, $p = .792$ ($M_{\text{left}} = 14.8$, $SD = 0.7$; $M_{\text{right}} = 14.9$, $SD = 0.7$).

Discussion

In this study we investigated the role of body position and empathy in joint numerical cognition. We found that the relative spatial position of a person influenced the magnitude of randomly generated numbers: Individuals generated smaller numbers when they were sitting to the left of another person, whereas they generated larger numbers when sitting to the right of another person. An influence of spatial body position (i.e., sitting on the left vs. right side of a table) was absent when participants performed the same task alone or with a non-human co-actor. Also, the mere presence of another person on the left or right side did not induce a bias in RNG, confirming that the bias observed in the joint condition can be attributed to the interaction with the other person. Interestingly, number magnitudes were not biased *toward* the co-actor's side, as one could expect due to attentional shifts along the mental number line (cf. Introduction). Rather, the observed pattern suggests that participants preferred to select numbers from the mental number line that spatially corresponded to their own physical body position relative to the other person, as if the two individuals were attending to different parts of a joint mental number line. This 'mental separation' from the co-actor might stem from a need for own space as a compensatory reaction to the personal space invasion in the joint condition (Terry & Lower, 1979). In fact, attentional shifts away from the other person have recently been related to social discomfort (Szpak et al., 2015). However, in the present study,

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individuals were acquainted, and the spatial bias was more pronounced for individuals with higher empathic concern, suggesting that our results are rather the consequence of the integration of the co-actor into a shared mental representation than attentional withdrawal from the co-actor due to social discomfort.

Our results are in line with the general idea of a shared task representation during joint coordination (Sebanz et al., 2006). However, our results cannot be explained by action co-representation: There was no priming of the co-actor's action and consequently no conflict due to motor simulation of the co-actors action, as it was the case in previous studies (Atmaca et al., 2008; Sebanz et al., 2003). Our results therefore suggest that joint compatibility effects do not necessarily depend on motor mirroring mechanisms (Atmaca et al., 2008; Kuhbandner, Pekrun, & Maier, 2010). Instead, spatial reference coding seems to be the crucial factor, shaping the way how a task and the individual's and co-actor's contribution to that task are represented.

The integration of one's own relative position into a numerical task does not seem to happen automatically upon the initial sharing of a task. In this study, the spatial bias emerged only after participants swapped their spatial positions. The act of changing positions may have activated or augmented the spatial relationship between the actor and co-actor, allowing for referential coding in the number selection process. This result is in line with the idea that a salient spatial event, in this case a change in position, is important for referential coding (Dolk et al., 2011; Dolk et al., 2013). Crucially, the change of position in the single condition (Experiment 1), or the change of position with a passive person and a loudspeaker (Experiment 2) is also likely to make the spatial frame of reference more salient. Particularly, moving from one side of the table to the other may increase awareness of the spatial relationship between the actor and the other spatial reference points of the experimental situation (e.g., the empty chair, the side of table, the passive person, the loudspeaker). However, no effect on number selection was observed in these cases. Thus, referential coding

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may depend on a salient reference point that emphasizes the spatial frame of reference of the dyad, which (at least in this study) was induced only by joint task performance with a human co-actor.

Interestingly, the effect of relative body position on RNG was mainly driven by participants with high empathic concerns toward others. This trait seems to boost the spatial coding of oneself relative to others. A possible explanation would be that empathic concerns toward others increase their salience as reference for own action/cognition (see Dolk et al., 2014, for a similar argumentation). In contrast, the effect of body position was not related to the other three sub-dimensions of empathy measured by the IRI. Personal distress and fantasy scale do not directly capture sensitivity towards others in social situations (Paulus, 2009), and the lack of correlation may not be too surprising. More intriguingly, there was no correlation with perspective taking, which captures the ability to take other's viewpoints. This particular ability has been shown to mediate effects of joint action in other contexts (Ford & Aberdein, 2015; Novembre et al., 2012), and a moderating role could also have been expected during joint RNG (Towse et al., 2016). A possible explanation for the absence of an effect of perspective taking might be that taking the viewpoint of the co-actor during RNG shifts the focus of attention toward the co-actor's side of the mental number line. An effect of referential coding on number selection may therefore be diluted for participants with a higher tendency to adopt their co-actor's viewpoint. While the exact role of empathy still remains open, this study points to a possible role of sympathy (i.e., the emotional and motivational state driven by the concern for others) in addition to the cognitive aspect of empathy (i.e., perspective taking) in the modulation of joint action/cognition effects. However, it should be noted that the correlation between empathic concern and the bias in RNG was only just significant, and that the results of the spatial bias within the low and high empathic concern groups (based on median split) was based on a limited sample size (n = 14 per group). The role of empathic concern therefore needs to be replicated in future studies. As a further

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limitation of this study, it remains an open question whether a role of empathic concern is exclusive for individuals that know each other (cf. Ford & Aberdein, 2015).

To our knowledge, joint compatibility effects have only been investigated in tasks where participants needed to decide whether a response is required or not (go-nogo), or where an explicit leftward or rightward spatial decision was required (Szpak et al., 2016). We showed that joint compatibility effects generalize to turn-taking situations in which not the decision to act, but rather the choice between seemingly arbitrary actions (i.e., which number to choose) was biased by the interpersonal situation. Relatedly, previous research attributed spatial compatibility effects to the spatial location of the response key (Welsh, 2009). We showed that, when verbal responses are required, the individual's body position determines the spatial reference frame (cf. Wenke et al., 2011).

To conclude, our results add to a growing body of research showing that the human mind acts differently when a task is performed alone than when it is performed together with another person. Our results suggest that spatial reference coding is a crucial mechanism that underlies joint compatibility effects. The effect of relative body position is likely the result of a more general tendency to construct a common representational space with egocentric coordinates, which may serve as basis for any social interactions, and interestingly, also shapes seemingly abstract cognitive processes such as number processing.

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Figure Captions

Figure 1. Experimental procedure of the joint (left part) and single (right part) random number generation (RNG) task. Participants changed their position(s) after 40 numbers. Examples of numbers in this figure are random and their greyscale in the joint condition signals number originates with one or the other participant.

Figure 2. Mean of generated numbers during the random number generation task for the left and right body position in the joint and single conditions. The asterisk indicates a significant difference between the left and right position in the joint condition. Error bars depict +/- 1 *SEM*.

Figure 3. Mean of generated numbers during the random number generation task for the left and right body position before and after the position change with the co-actor in the joint condition. The asterisk indicates a significant difference between the left and right position after the position change. Error bars depict +/- 1 *SEM*.

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Table 1

Mean empathy scores for the two experimental groups and correlations between the differences in RNG (right-left position) and empathy of participants in the joint condition

	Experimental Condition				Correlation between RNG_{Diff} and Empathy	
	Single (n = 34)		Joint (n = 32)			
Empathy	*M*	*SD*	*M*	*SD*	*r*	*p*
Empathic concern	15.3	2.6	14.6	2.5	.370*	.037
Perspective taking	15.4	2.6	15.1	2.2	-.126	.491
Fantasy scale	13.5	3.5	13.4	2.4	.032	.864
Personal distress	11.3	2.5	10.8	2.9	.096	.601

Note. M = mean (test score), SD = standard deviation, r = Spearman correlation between the difference in mean random numbers generated in the right and left spatial position ($RNG_{Diff} = M\ RNG_{right} - M\ RNG_{left}$) and empathy of participants in the joint condition.

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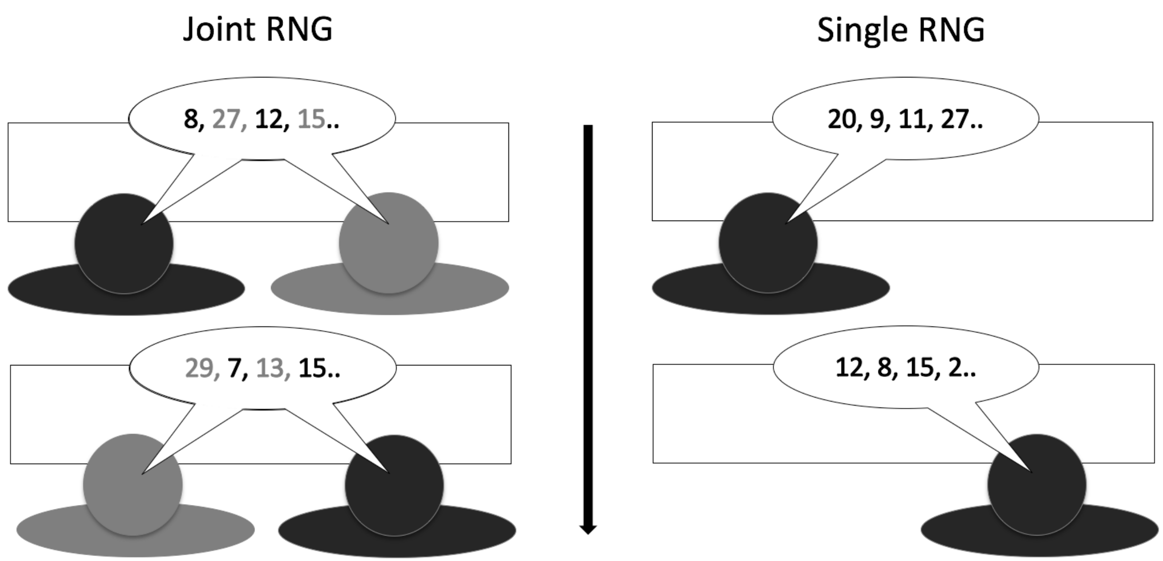

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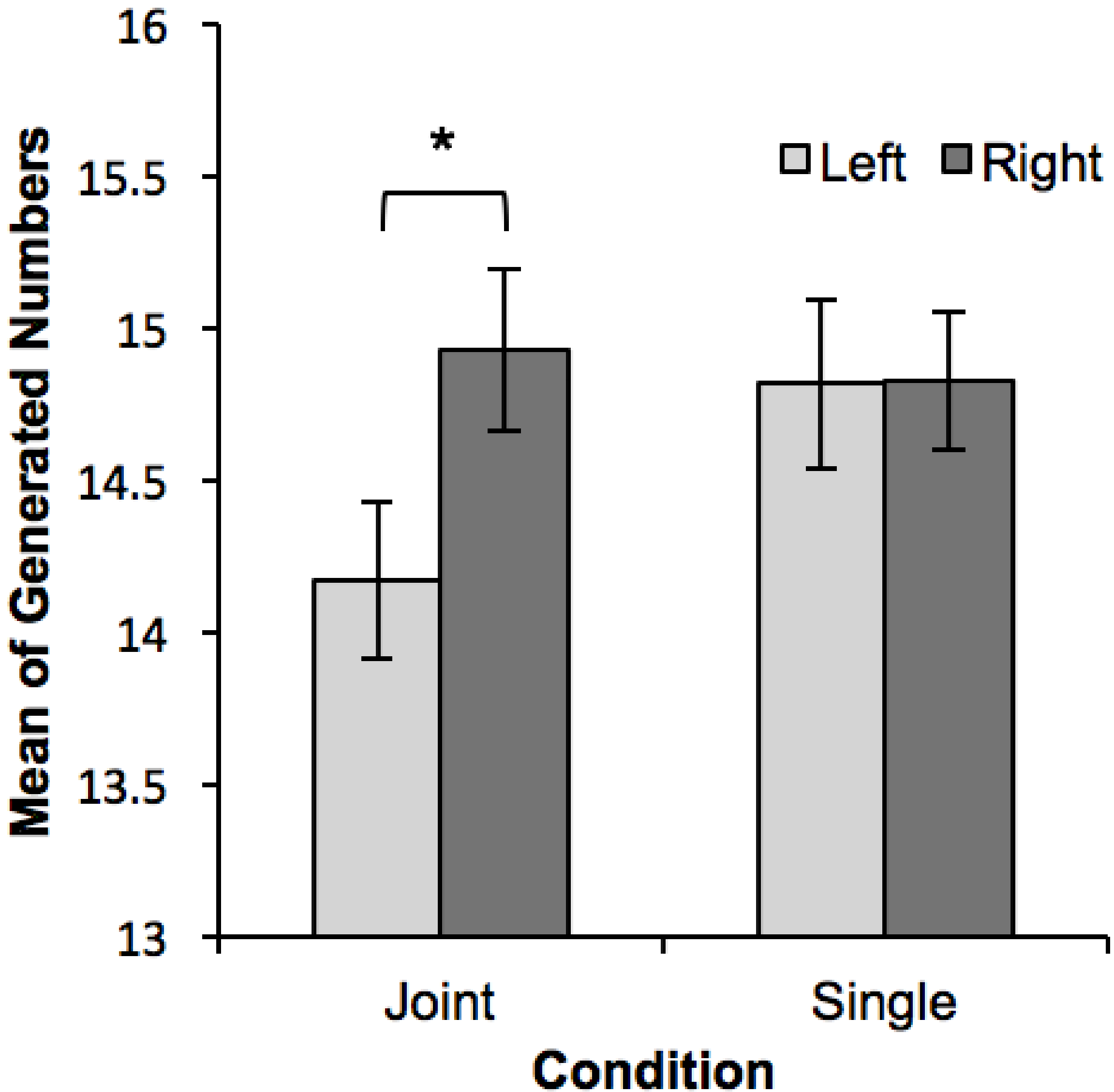

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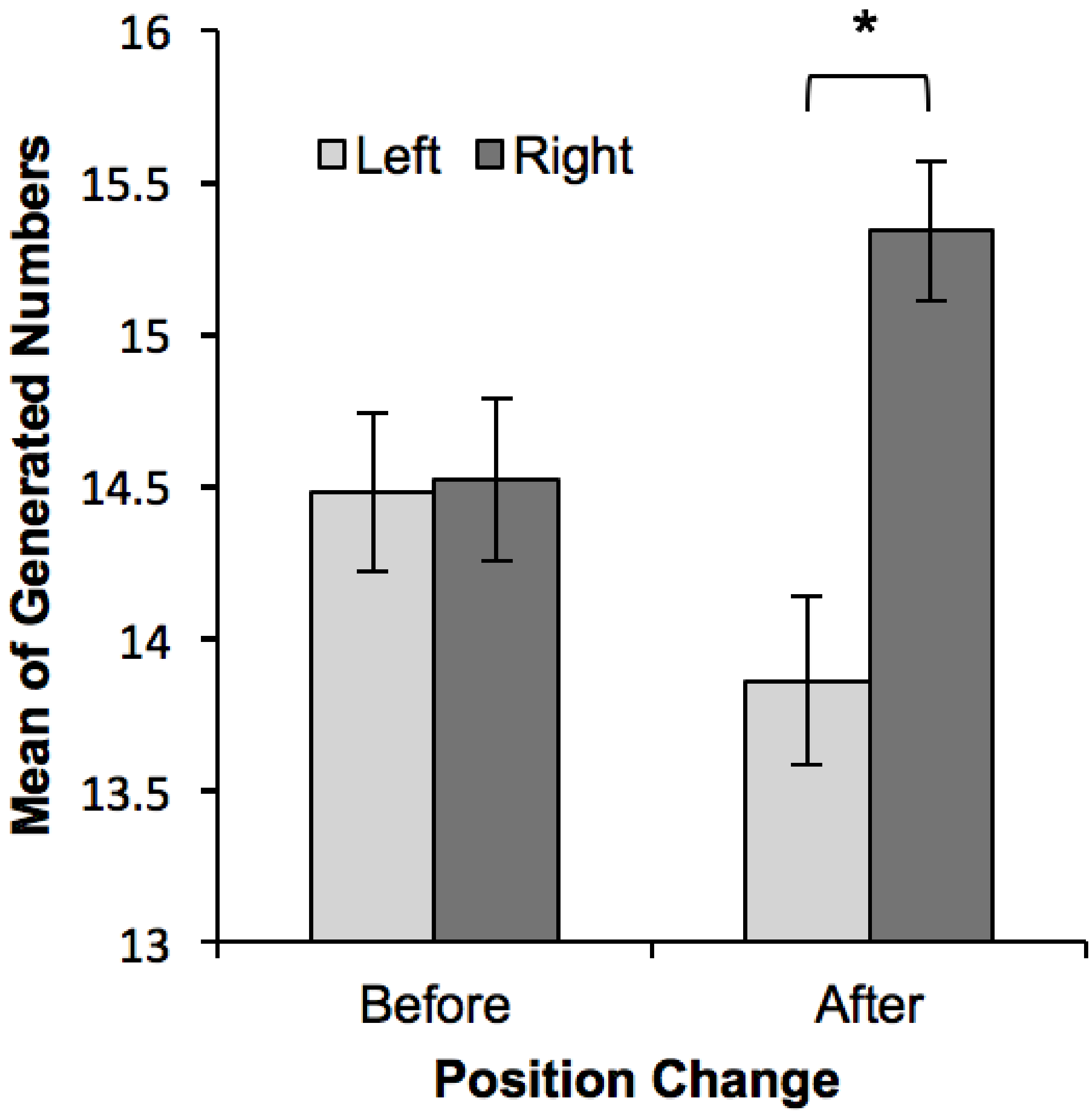

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